

# Physics with CMS Hadron Calorimeter

Shuichi Kunori

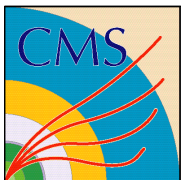
U. of Maryland

24-Nov-2000

Jet,MET,tau

Some physics channels

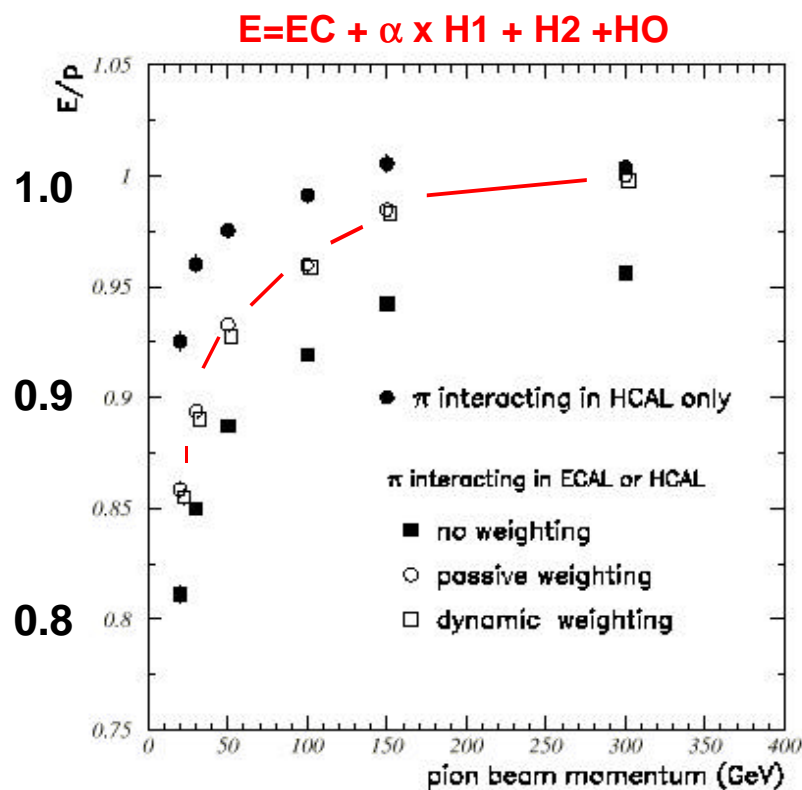
Calibration



# Pion Response: Linearity

ECAHL+HCAL: Non compensating calorimeter

96'H2 Teast Beam Data



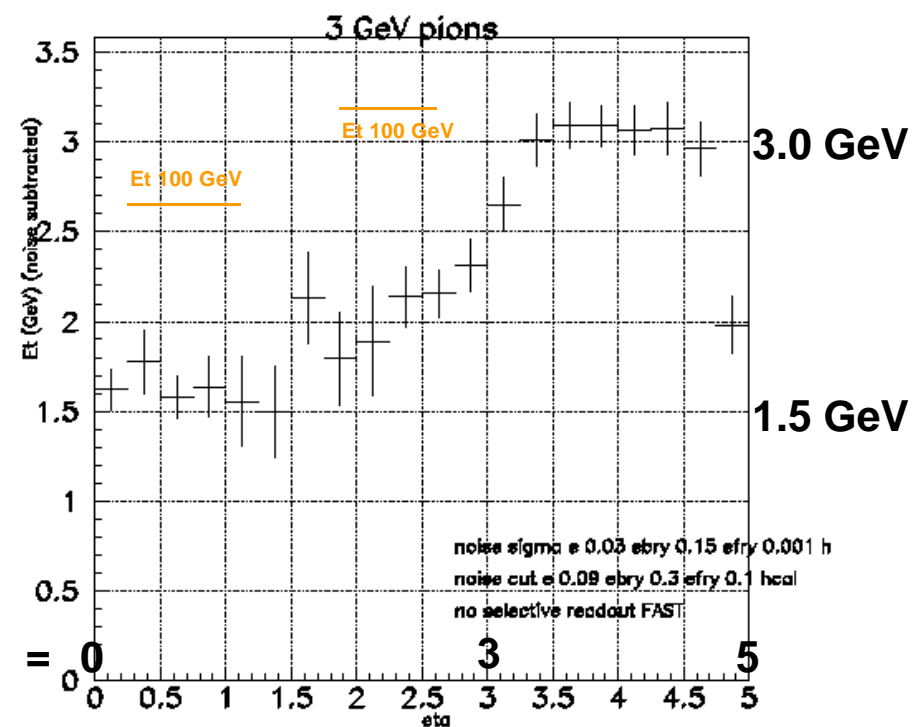
P= 0

200

400GeV

CMS Simulation

ET=3 GeV pion in  $0 < |\eta| < 5$



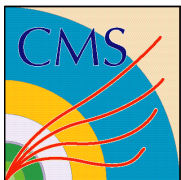
E= 3

7

30

82

227 GeV

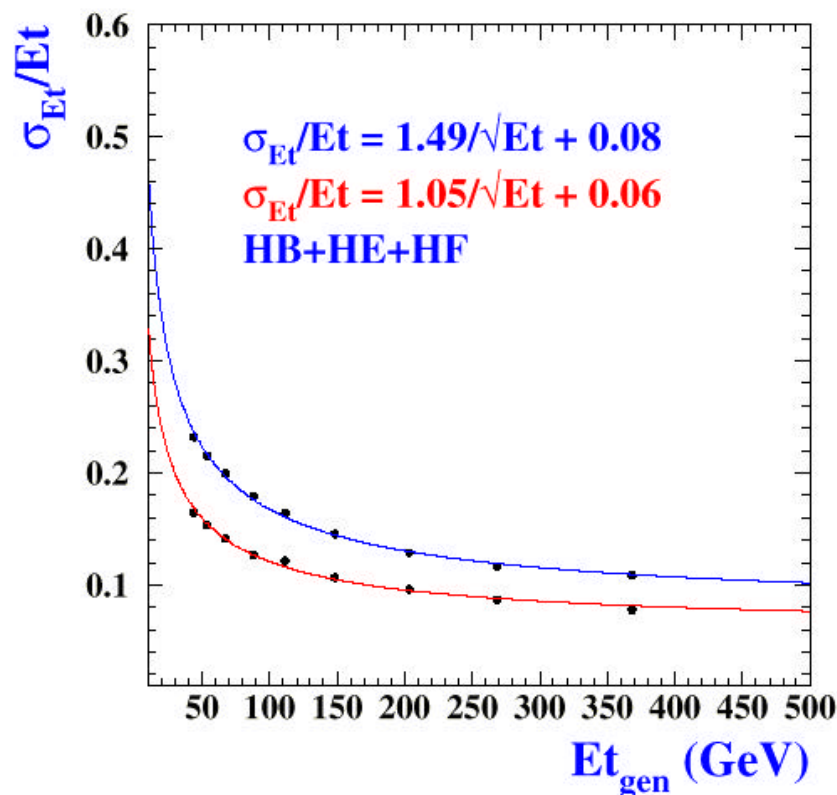
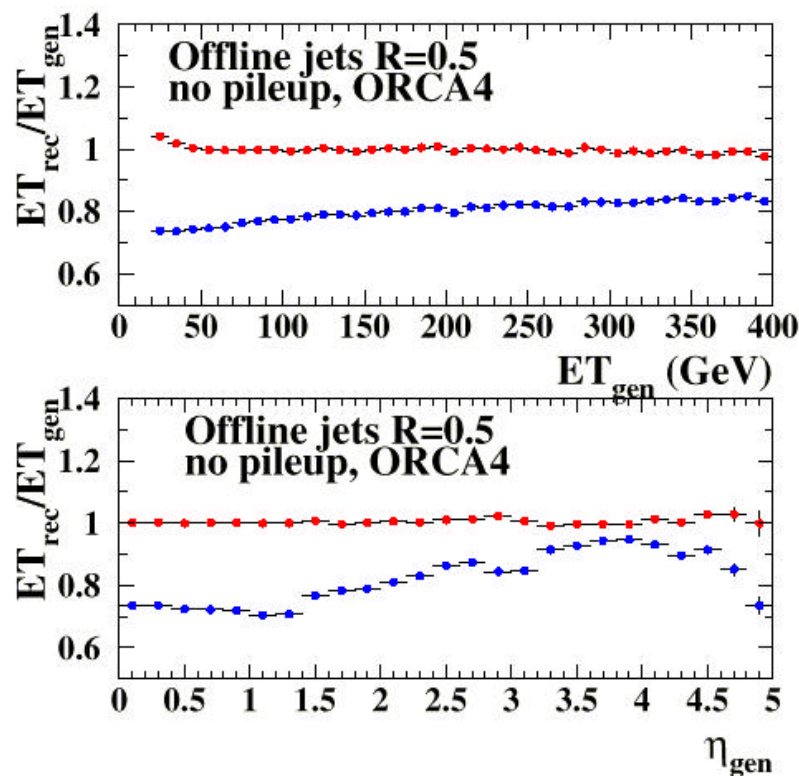


# Jet Response and Correction ( CMSIM/ORCA)

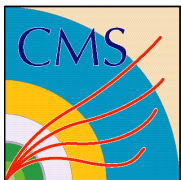
Et-eta dependent correction for QCD jets

$$Et(\text{corr}) = a + b \times E_T(\text{rec}) + c \times E_T(\text{rec})^2$$

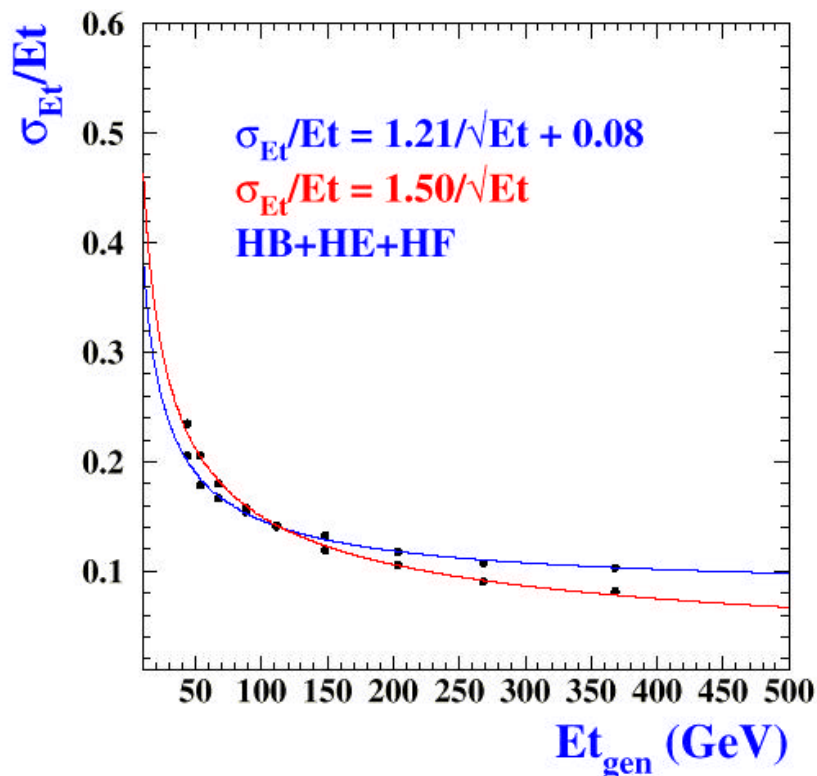
No-pileup



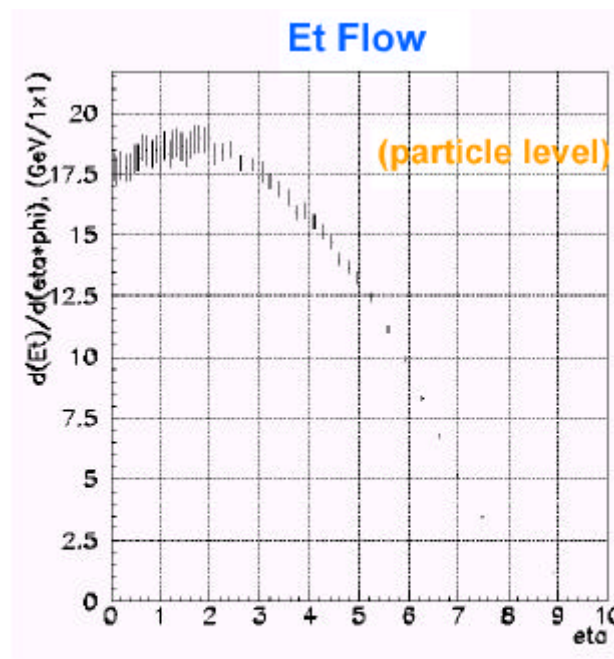
=> Different corrections for L1 jets, tau-jets and b-jets  
 => Luminosity dependent.



# Correction and Pileup Energy @ 10E34



<17.3> in-time min-bias events



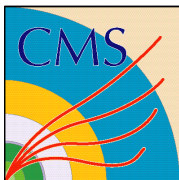
~17 GeV in unit ( $\eta \times \phi$ ) !

(equiv. cone radius 0.56)

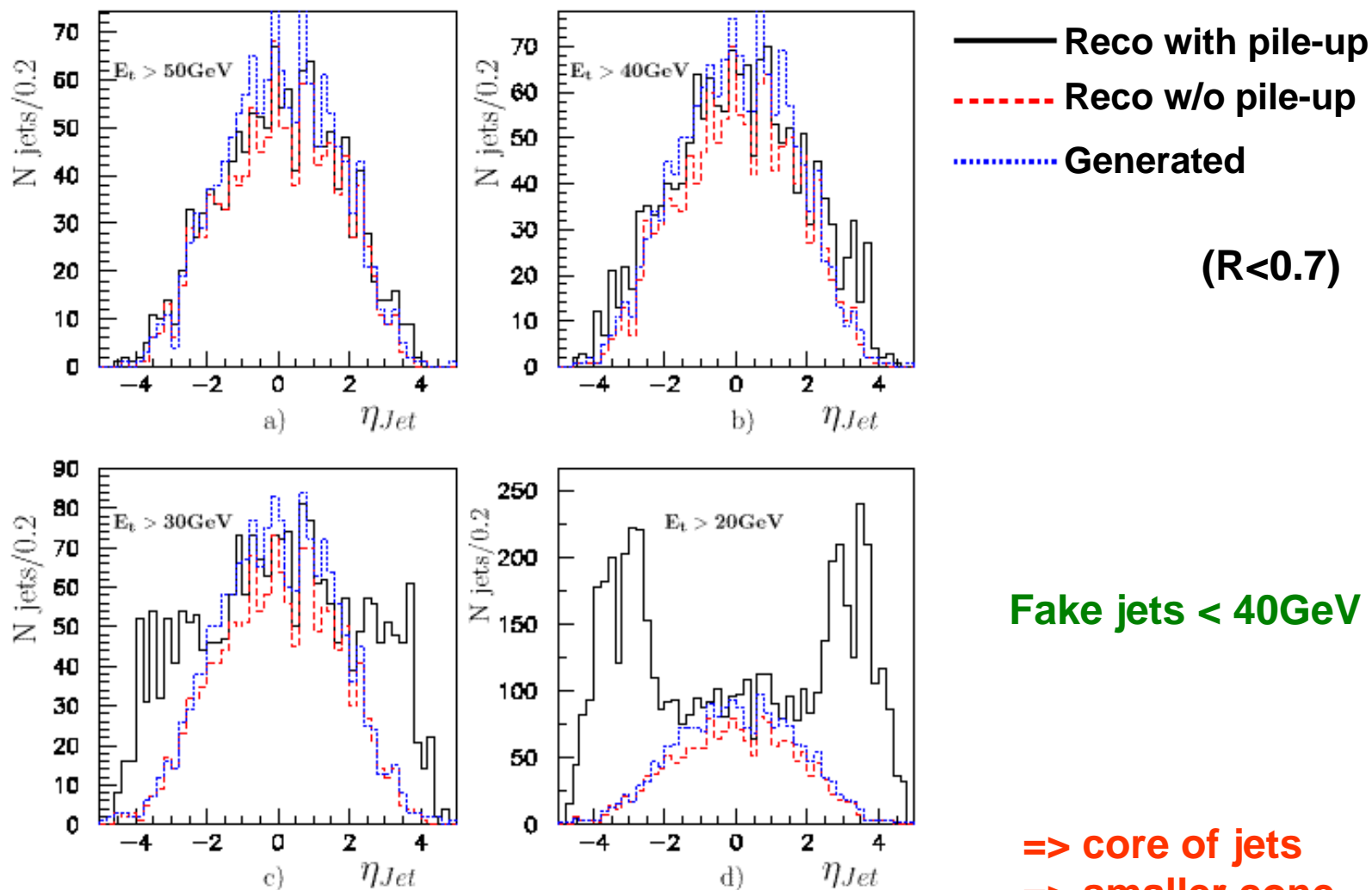
Resolution after corrections is worse because pileup fluctuations are not removed by the **average** correction.



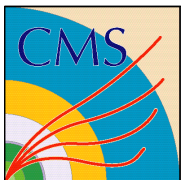
Event-by-event correction:  
e.g. algorithm developed for  
heavy ion collision. (I.Vardanian)



# Low Et Jets and Pile-up



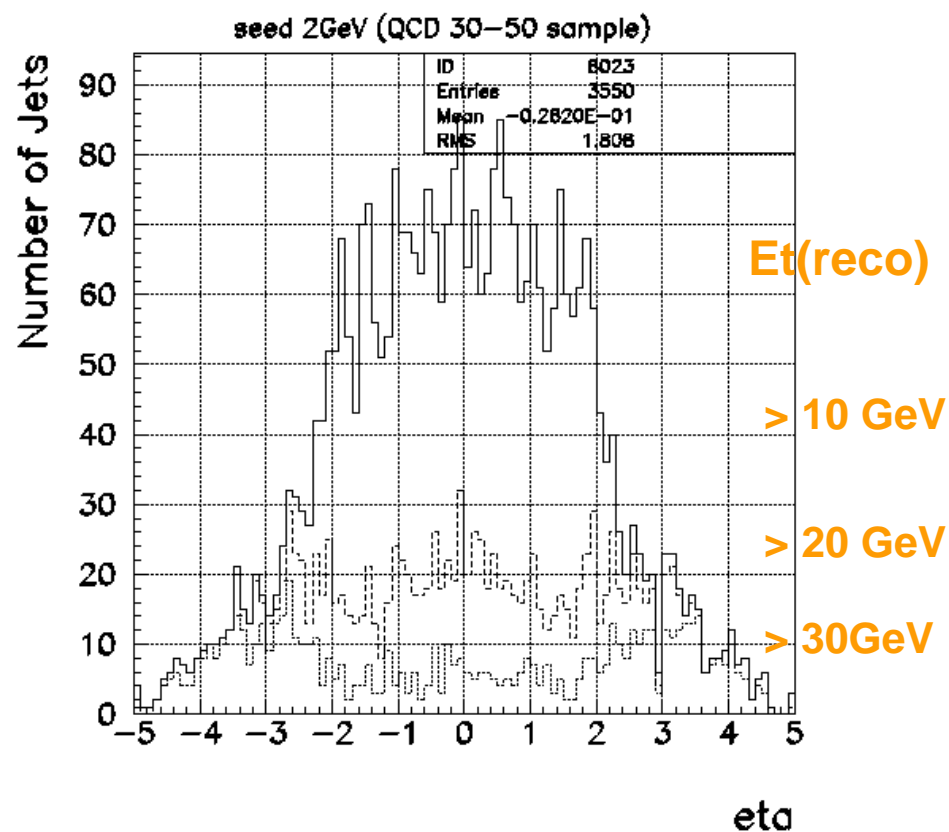
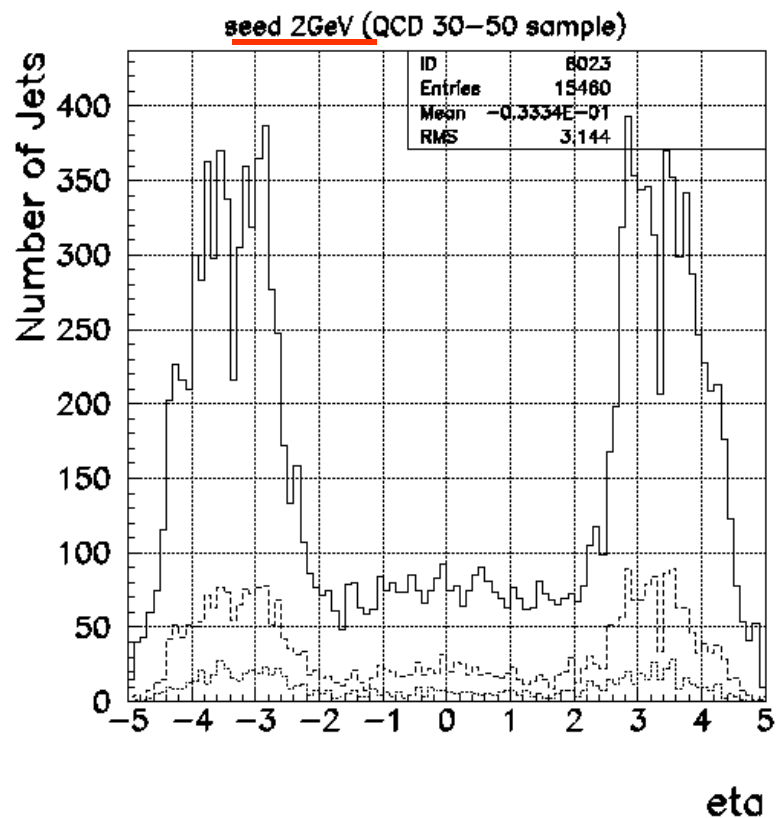
(A.Krokhovine)



# Seed Cut

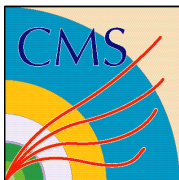
No cut

2 GeV / (0.087x0.087)



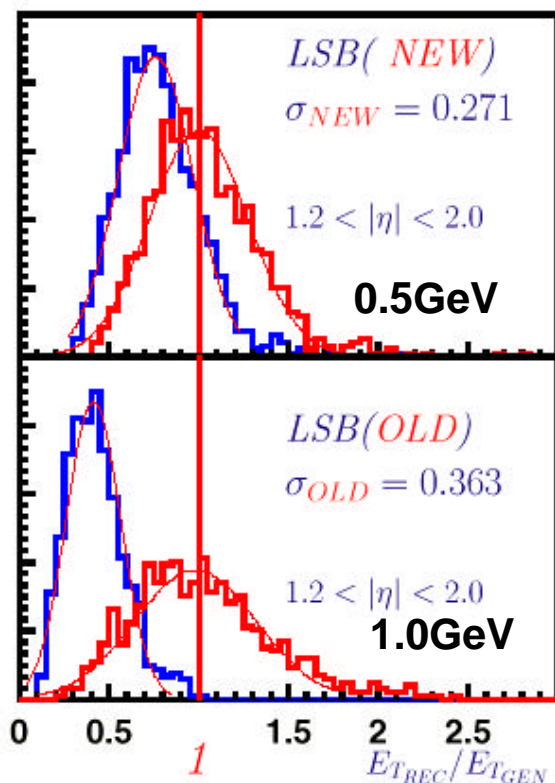
Suppression of fake jets!

... but still many fakes remaining.



# Low $E_T$ Jets and Threshold

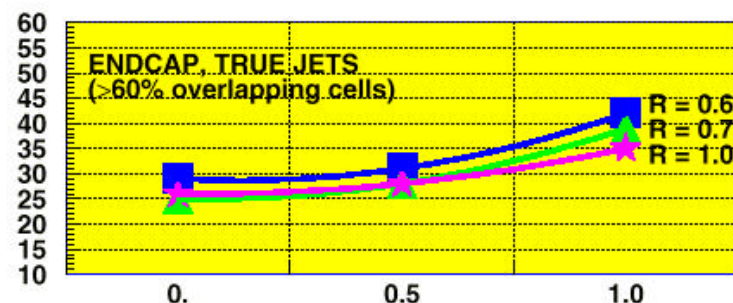
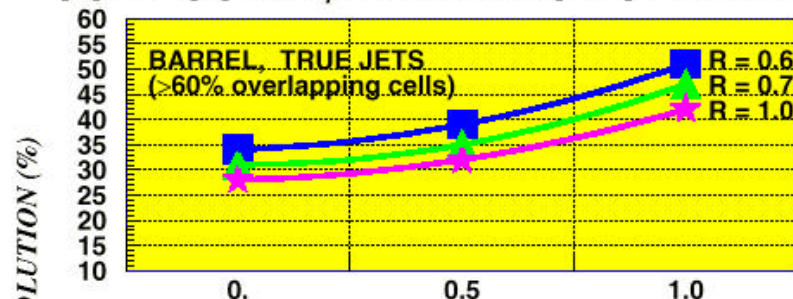
$35 < E_T(\text{gen}) < 45 \text{ GeV}$



(A.Krokhotine)

$E_T(\text{quark}) = 20 \text{ GeV}$

$q+q_{\text{bar}} \rightarrow q+q_{\text{bar}} (E_{T\text{parton}} = 20 \text{ GeV})$  with pile-up ( $< 17.3 >$  min.bias)



THRESHOLD ON ECAL AND HCAL CELL ENERGY (GeV)

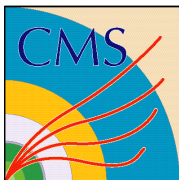
where  $RESOLUTION = \sigma((E_{T\text{jet}} - E_{T\text{parton}})/E_{T\text{jet}})$  (%),  
 $E_{T\text{jet}}$  - reco jet with pile-up and with threshold

(I.vardanian)

**Lower threshold is better!**

Electronics noise and occupancy define the threshold.

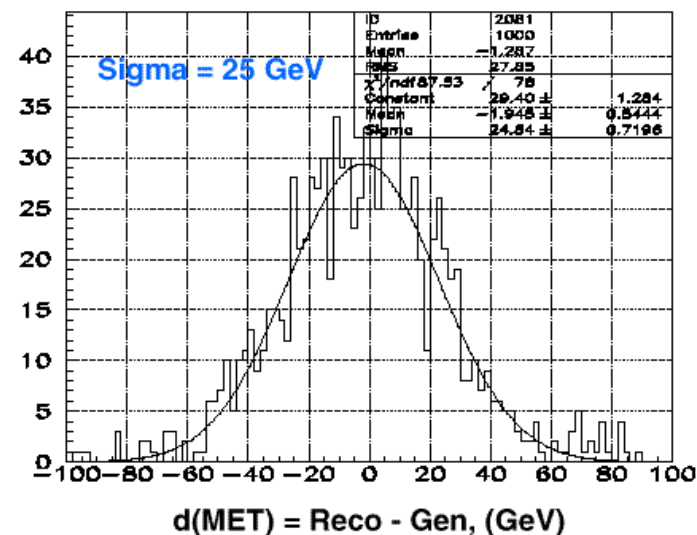
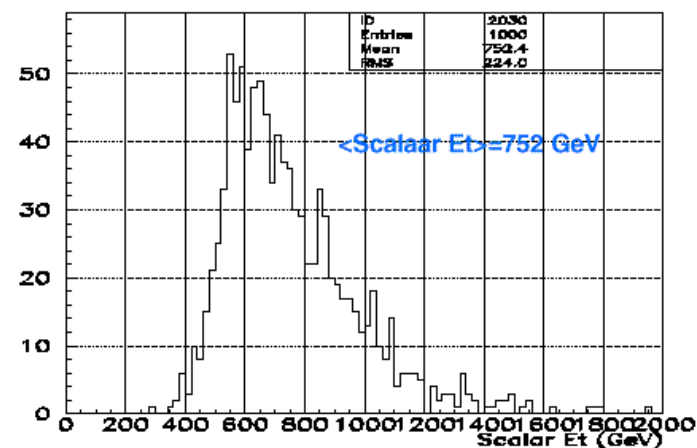
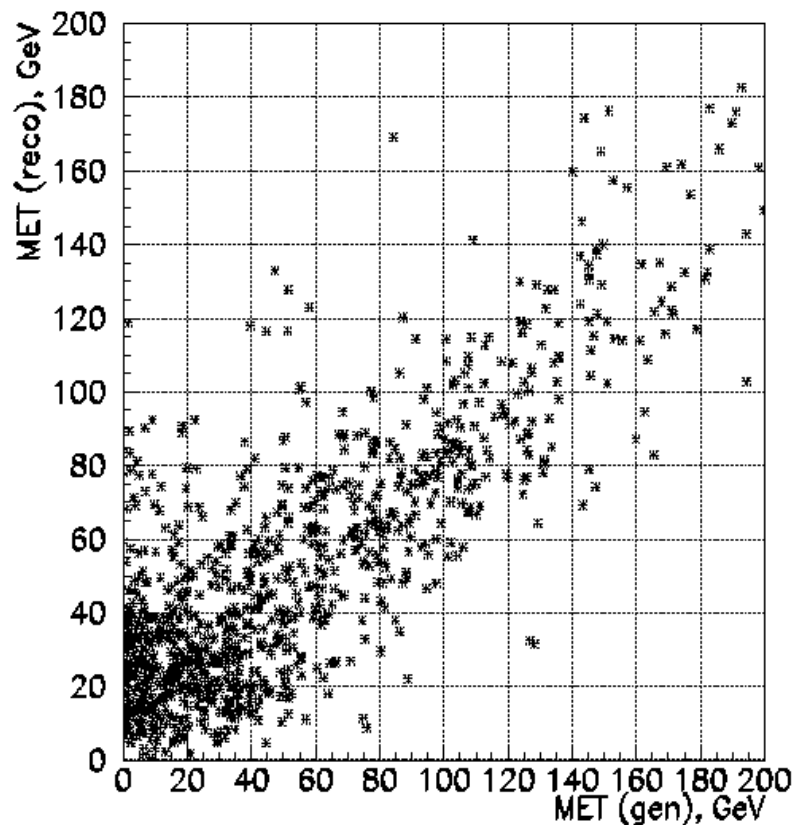
>> aim at **0.5 GeV/tower @ 10E34**



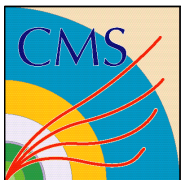
# MET Response

**ttH(110)** no min-bias overlap

(H→bb)



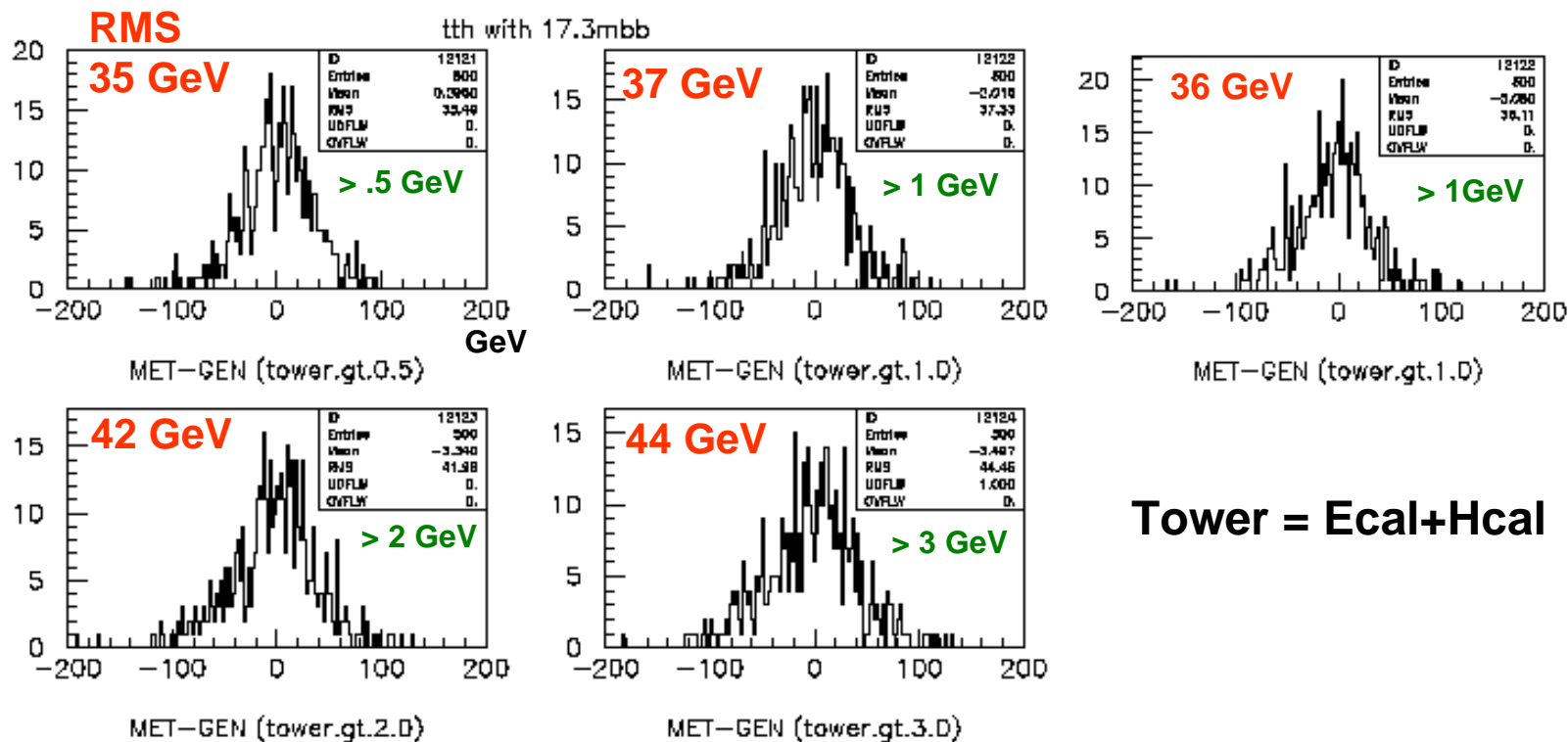
(0.5GeV Threshold)



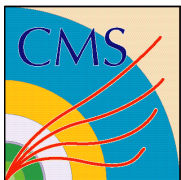
# MET for Signal Events with Pile-up and Tower Threshold

With 17.3 min-bias events

No min-bias

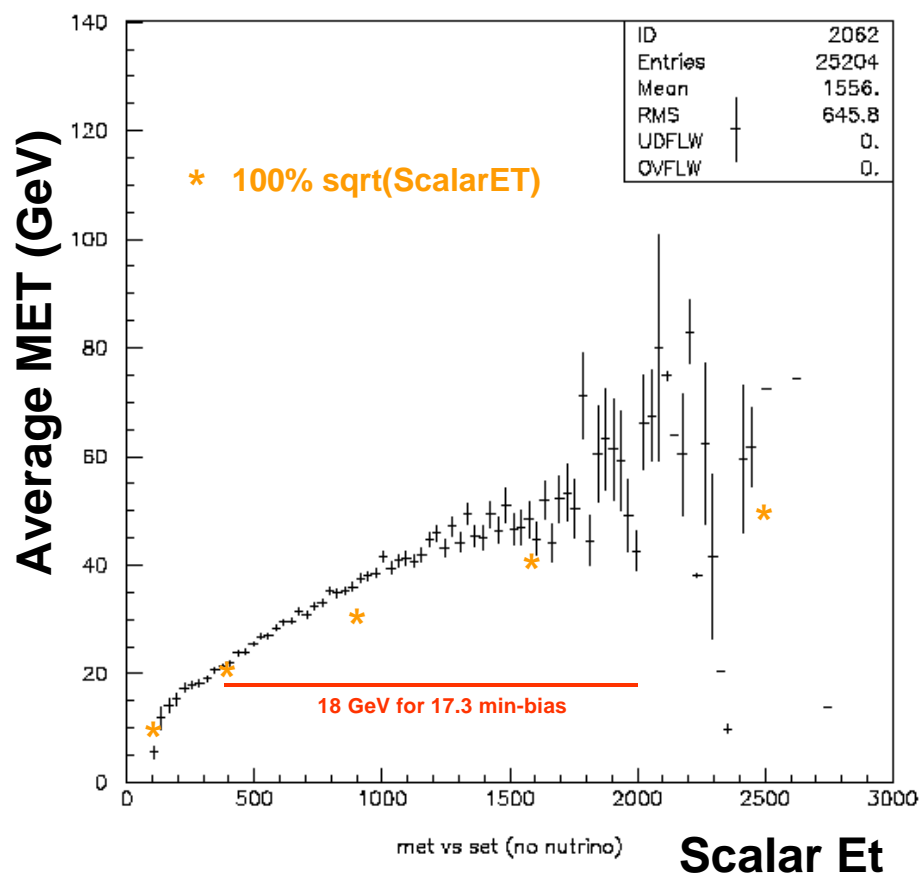


- >> Not much pile-up effect with this resolution!
- >> Resolution gets worse as threshold increase.



# MET Resolution

QCD Jets with no neutrino/muon  
(no pile-up)



$$E_x = \sum (E_{x\text{-tower}})$$

$$E_y = \sum (E_{y\text{-tower}})$$

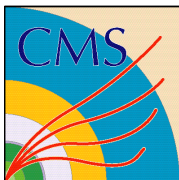
Any way to improve this?

e.g.

$$E'_x = E_x + \sum (\Delta(E_{x\text{-jet}}))$$

$$E'_y = E_y + \sum (\Delta(E_{y\text{-jet}}))$$

Does this work?

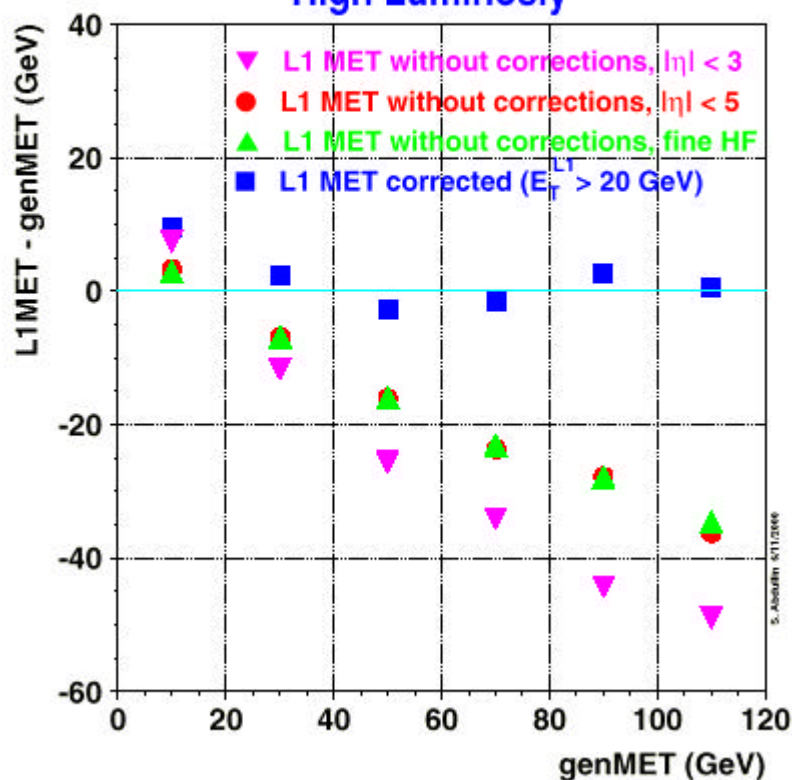


# Attempt to improve L1 MET with Jet Correction

$$\text{L1 MET} = \text{L1 MET} + \sum E_{t \text{ L1J}}^{\text{corr}} - E_{t \text{ L1J}}^{\text{no corr}}, \text{ for } E_{t \text{ L1J}} > 20 \text{ GeV}$$

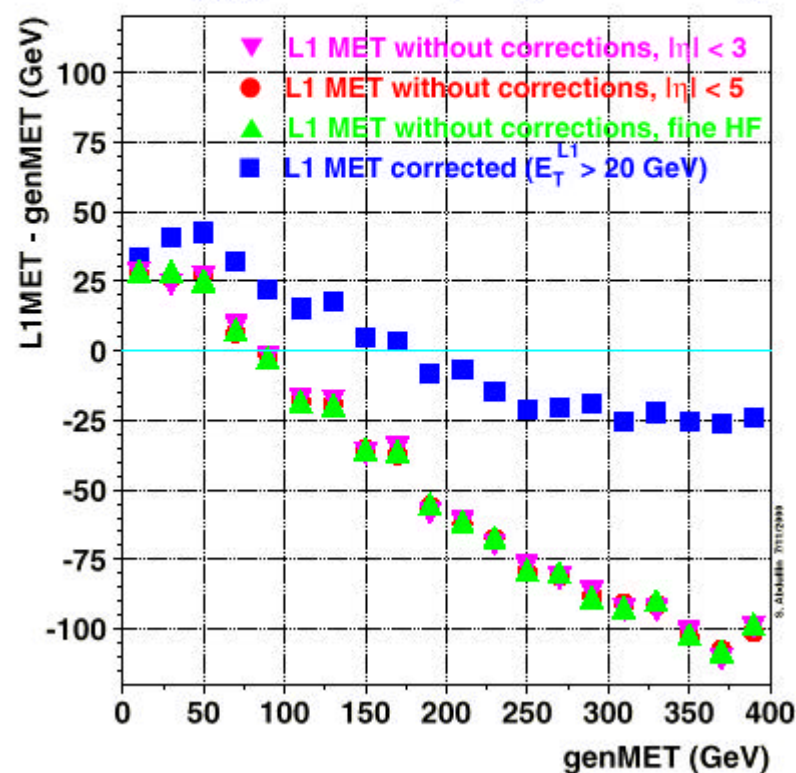
qq->qqH(120 GeV), H->invisible

High Luminosity

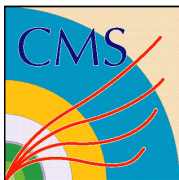


for mSUGRA events : Jets + MET,

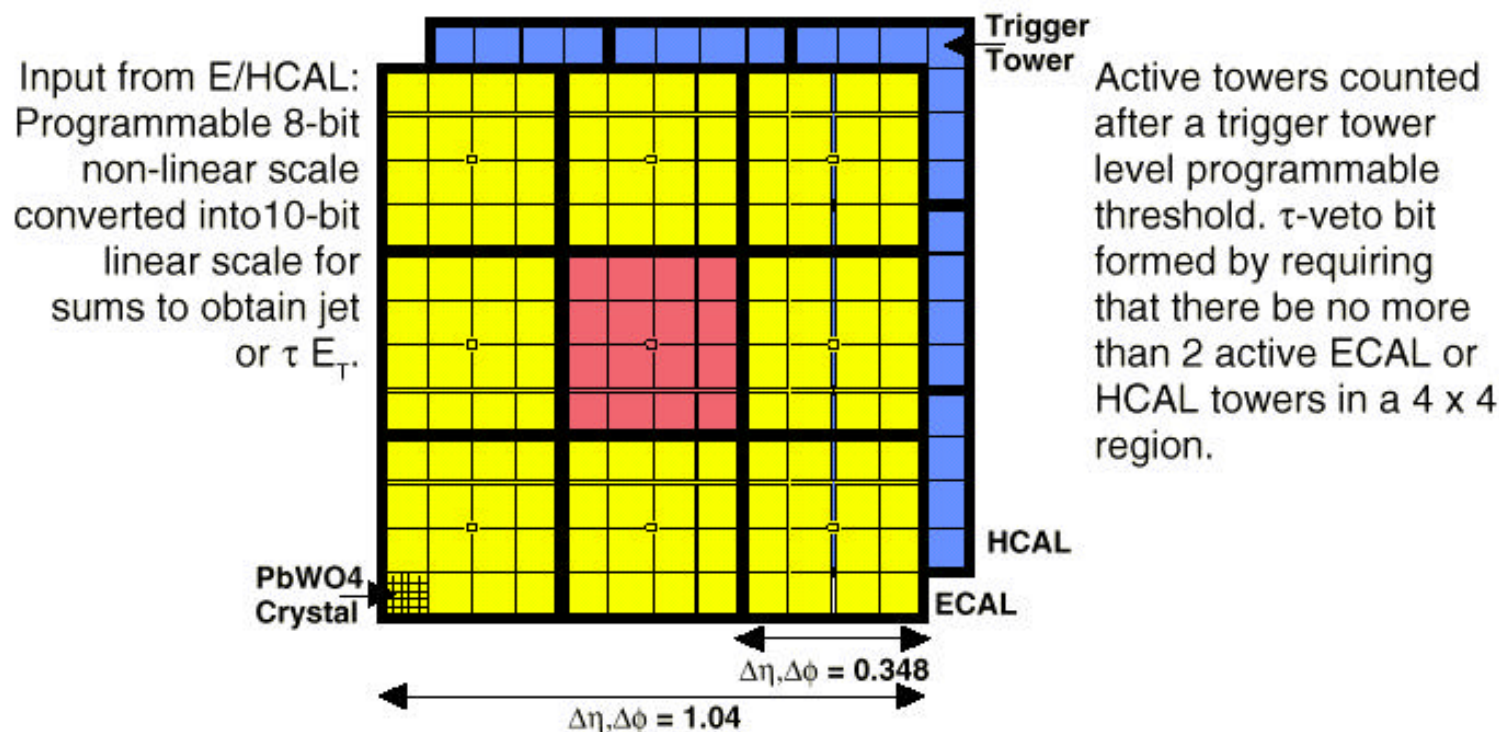
$M_{\text{SUSY}} \sim 500 \text{ GeV}$ , High Luminosity



(S.Abdouline)



# L1 Trigger- Jets/Tau



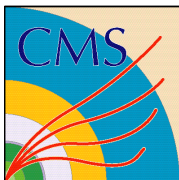
## Jet or $\tau E_T$

- 12x12 trigger tower  $E_T$  sums in 4x4 region steps with central region > others
- $\tau$  algorithm (isolated narrow energy deposits)

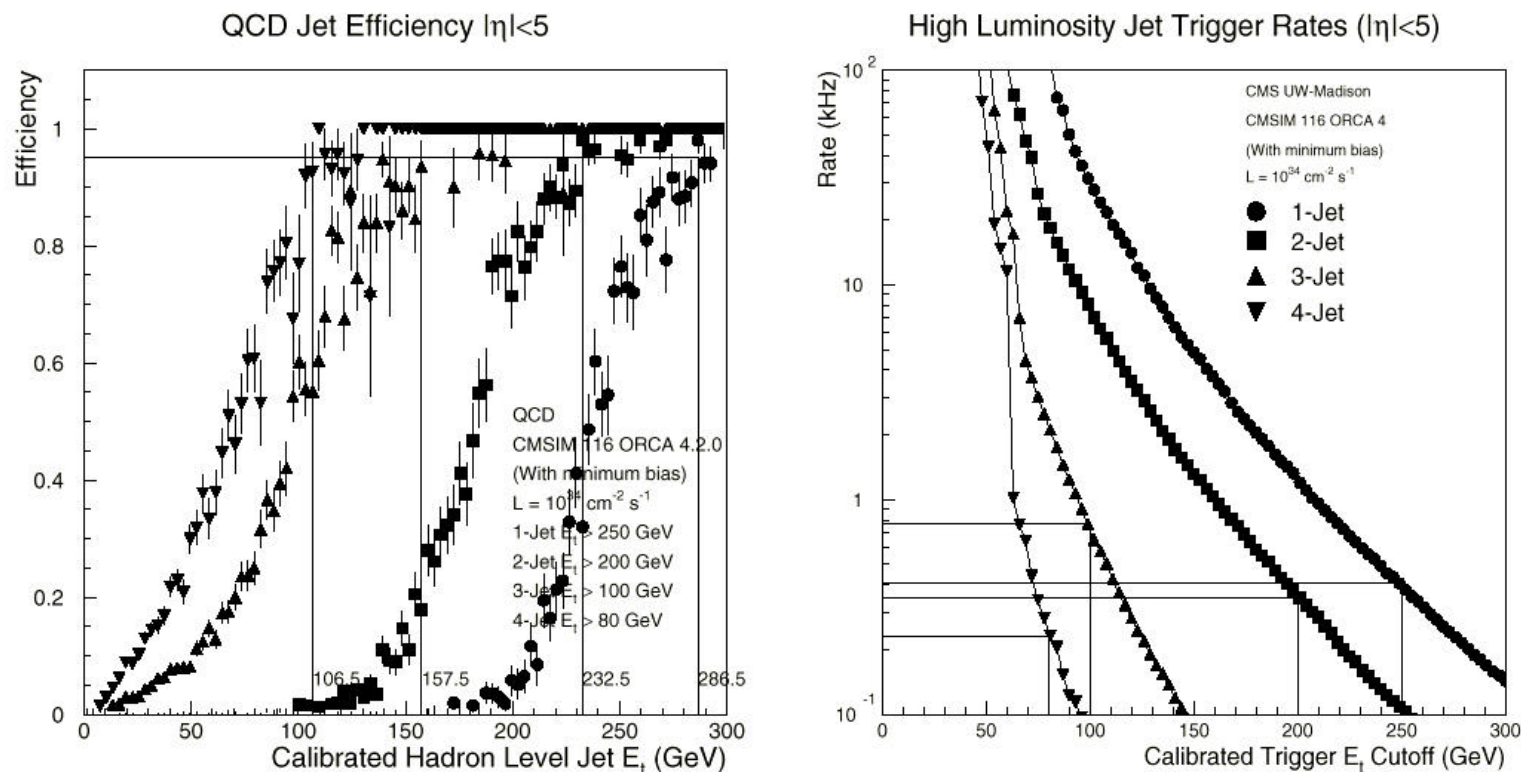
- Redefine jet as  $\tau$  jet if none of the nine 4x4 region  $\tau$ -veto bits are on

## Output

- Top 4  $\tau$ -jets and top 4 jets in central rapidity, and top 4 jets in forward rapidity



# L1 Jet Trigger



**$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$  with Pileup**

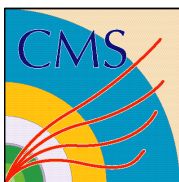
**Cutoffs of 250, 200, 100, and 80 GeV**

**Both vs. calibrated energy and jets to  $|\eta| < 5$**

**Cutoffs of 250, 200, 100, & 80 GeV with 95% efficiency at 285, 225, 125, & 105 GeV**

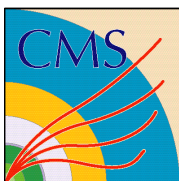
**Rates of 0.4, 0.4, 0.7, & 0.2 kHz**

(P.Chumney)



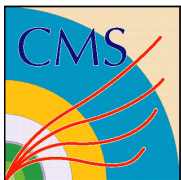
# Sample L1 Rates and Cutoffs @10E33

Trigger Type	Trigger $E_T$ Cutoff (GeV)	95% Efficiency Threshold (GeV)	90% Efficiency Threshold(GeV)	Incremental Rate (kHz)	Cumulative Rate (kHz)
Non-Iso Electron	20	24	22	5.73	5.73
Non-Iso Dielectron	10	14	12	2.65	7.44
Single Tau	80	95	85	3.23	9.85
Double Tau	60	75	65	1.50	10.34
Jet ( $ \eta <5$ )	120	150	140	1.19	10.80
Dijet ( $ \eta <5$ )	90	115	105	1.01	10.90
Trijet ( $ \eta <5$ )	70	95	85	0.33	10.91
Quadjet ( $ \eta <5$ )	50	75	65	0.33	10.99
Jet · Electron	100 & 10	125 & 14	115 & 12	1.11	11.10
Tau · Electron	65 & 10	80 & 14	70 & 12	3.50	11.87
Missing $E_T$ ( $ \eta <5$ )	100		275	0.01	11.87
Electron · $ME_T$ ( $ \eta <5$ )	10 & 50		12 & 175	0.15	11.90
Jet · $ME_T$ ( $ \eta <5$ )	50 & 50		65 & 175	0.63	12.24
Sum $E_T$ ( $ \eta <5$ )	500		~1000	0.02	12.24
Total Rate					12.24



# Sample L1 Rates and Cutoff @ 10E34

Trigger Type	Trigger $E_T$ Cutoff (GeV)	95% Efficiency Threshold (GeV)	90% Efficiency Threshold(GeV)	Individual Rate (kHz)	Cumulative Rate (kHz)
Iso-Electron	30	35	32	7.21	7.21
Iso-Dielectron	15	20	18	0.59	7.47
Single Tau	150	175	165	1.27	8.71
Double Tau	80	105	95	2.52	10.86
Jet ( $ \eta <5$ )	250	285	275	0.40	11.16
Dijet ( $ \eta <5$ )	200	225	215	0.36	11.25
Trijet ( $ \eta <5$ )	100	125	115	0.72	11.58
Quadjet ( $ \eta <5$ )	80	105	95	0.24	11.61
Jet · Electron	150 & 15	165 & 20	155 & 18	0.24	12.70
Tau · Electron	90 & 15	125 & 20	115 & 18	1.38	12.24
Missing $E_T$ ( $ \eta <5$ )	150		350	0.005	12.24
Electron <sup>1</sup> · $ME_T$ ( $ \eta <5$ )	15 & 100		18 & 250	0.005	12.24
Jet · $ME_T$ ( $ \eta <5$ )	80 & 100		95 & 250	0.1	12.29
Sum $E_T$ ( $ \eta <5$ )	1000		~1500	0.03	12.32
Non Iso-Electron	55	60	58	0.65	12.78
Non Iso-Dielectron	25	30	28	0.21	12.93
Total Rate					12.93

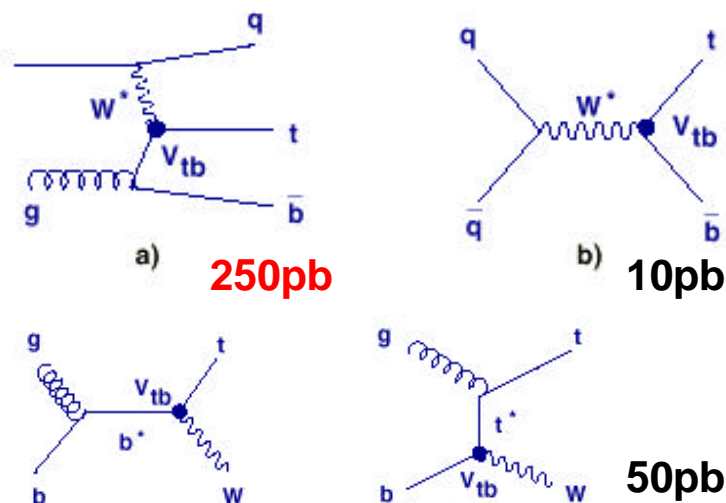


# Single Top $\rightarrow$ Wb $\rightarrow$ l**v**b

CMS Note 1999/048

## Measurement of

- $V_{tb}$
- properties and decays of top
- background process to new physics



## Background:

- top+top 800pb
- W+2jets
- W+3jets

## Event Selection:

only one charged lepton

$PT > 20\text{GeV}$  in  $|\eta| < 2.5$

only one central jet

$ET > 20\text{GeV}$  in  $|\eta| < 2.5$

(jet veto against tt)

b-tagged ( $20 < ET < 100\text{GeV}$ )

forward tagging jet

$ET > 50\text{GeV}$  in  $2.5 < |\eta| < 4.0$

MET

$> 20\text{GeV}$

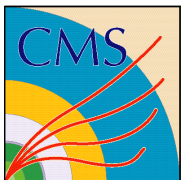
W Mass (lepton + MET)

$50 < MT < 100\text{GeV}$

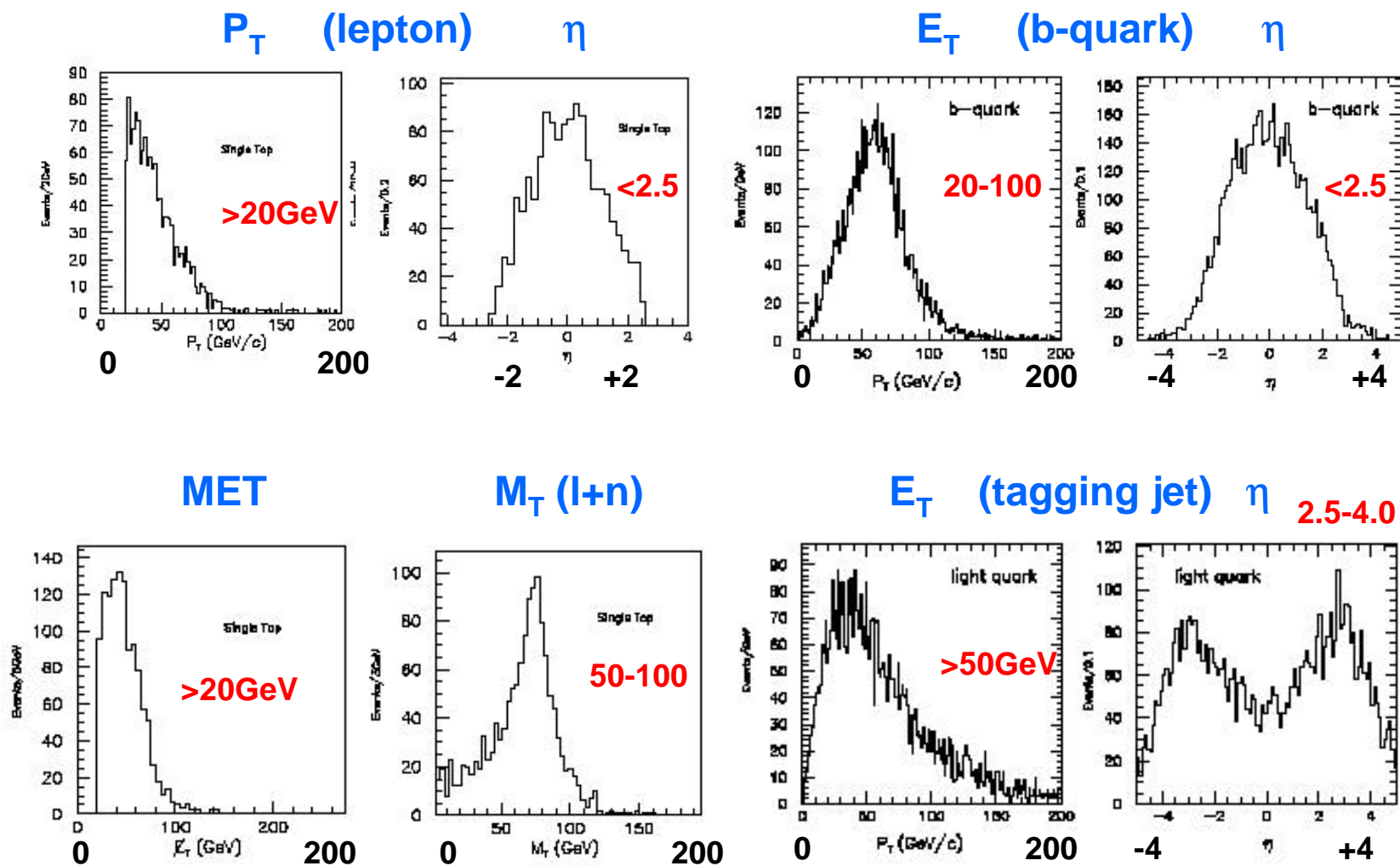
Di-jet mass outside  $M(Z^0)$

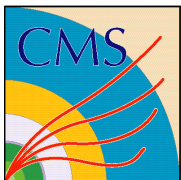
top mass cut

$140 < M(Wb) < 180\text{GeV}$



# Single Top - Kinematics

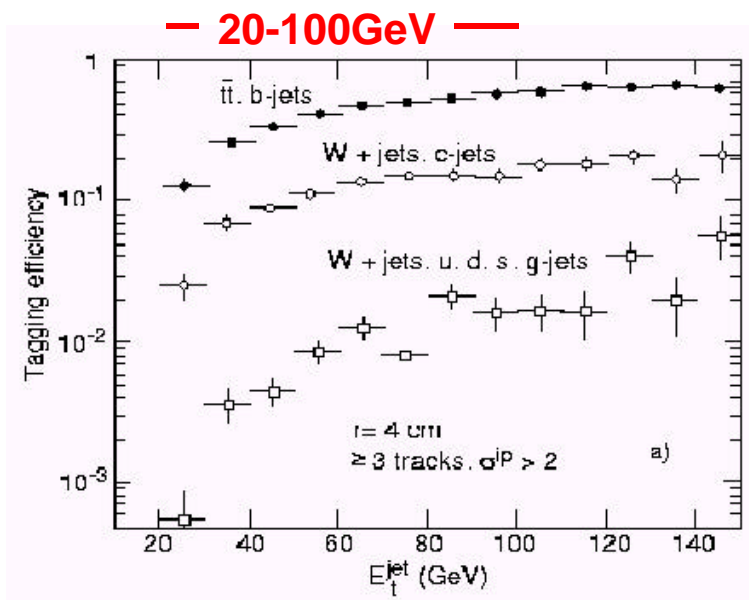




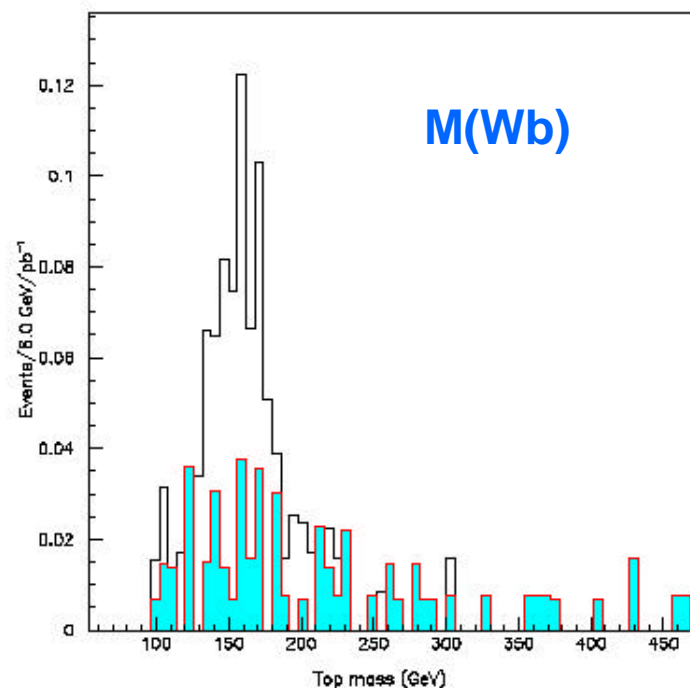
# Top Mass

## b/c tagging efficiency and fake

- very old parametrization used in this analysis-

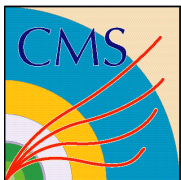


Charm rate and fake rate play important role in background rejection.



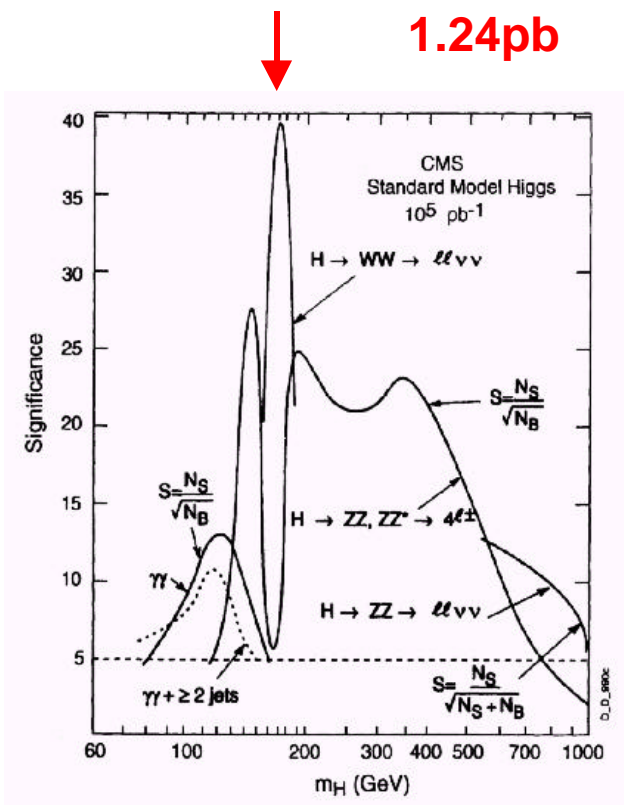
**S / N = 3.5 / 1.0**

**66 signal events / 100pb**  
**30 hours @ 10E33.**  
**Efficiency: 1.2%**



# H(170) -> WW -> lνlν

(CMS Note 1998/089)



## Event Selection:

(total 11 cuts)

two opposite sign leptons

- PT cuts (20GeV,10GeV)

- angle between two leptons

jet veto

- ET > 20GeV in  $|\eta| < 2.4$ : removed

Mass (WW)

- M > 140GeV

## Results:

- number of events (5fb<sup>-1</sup>)

H / tt / WW = 54 / 35 / 28

- good channel for discovery

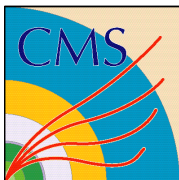
- background: need good understanding

- jet veto: important.

## Background:

tt -> (Wb)(Wb) -> (lνb)(lνb) 62.5pb

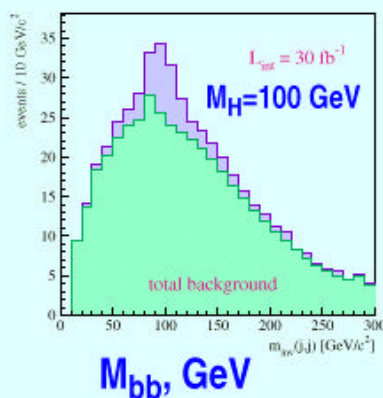
WW(continum) -> lνlν 7.4pb



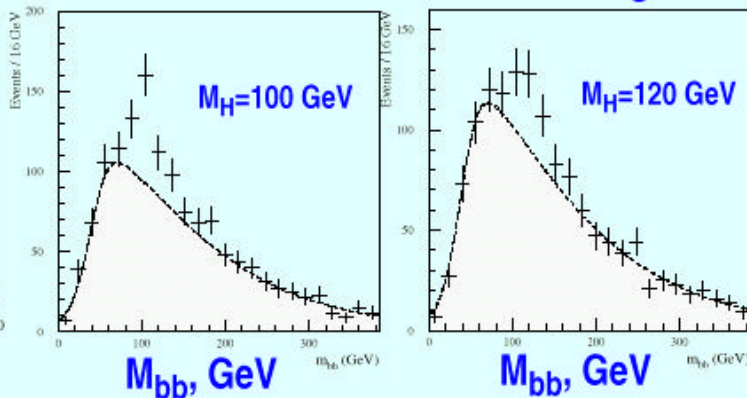
# $ttH(\sim 110) \rightarrow (lnb) (jjb) (bb)$

requires an excellent b-tagging and calorimeter performance

CMS.  $30 \text{ fb}^{-1}$  low lumi



ATLAS.  $30 \text{ fb}^{-1}$  low lumi +  $70 \text{ fb}^{-1}$  high lumi

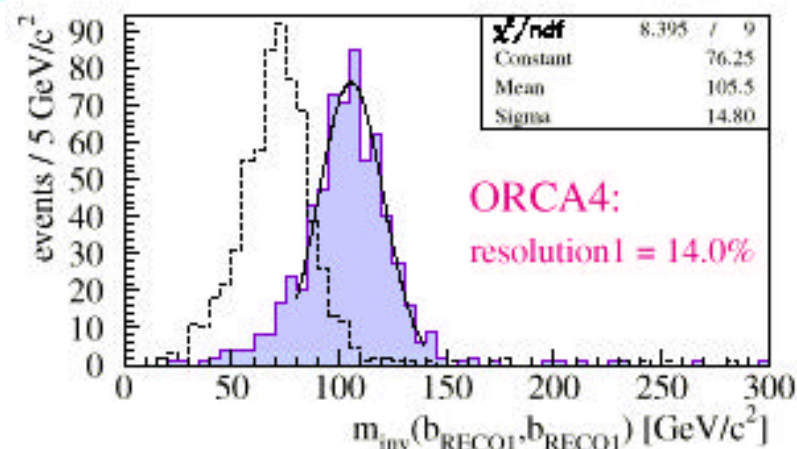


primary selection  
4 b-tags  
 $M(bb)$   
+  
lepton

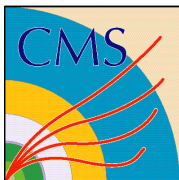
significance  $> 5$  can be achieved for SM Higgs  $80 < M_H < 120 \text{ GeV}$   
with  $100 \text{ fb}^{-1}$

$M(bb)$

Jet energy correction  
without: 19%  
with: 14%

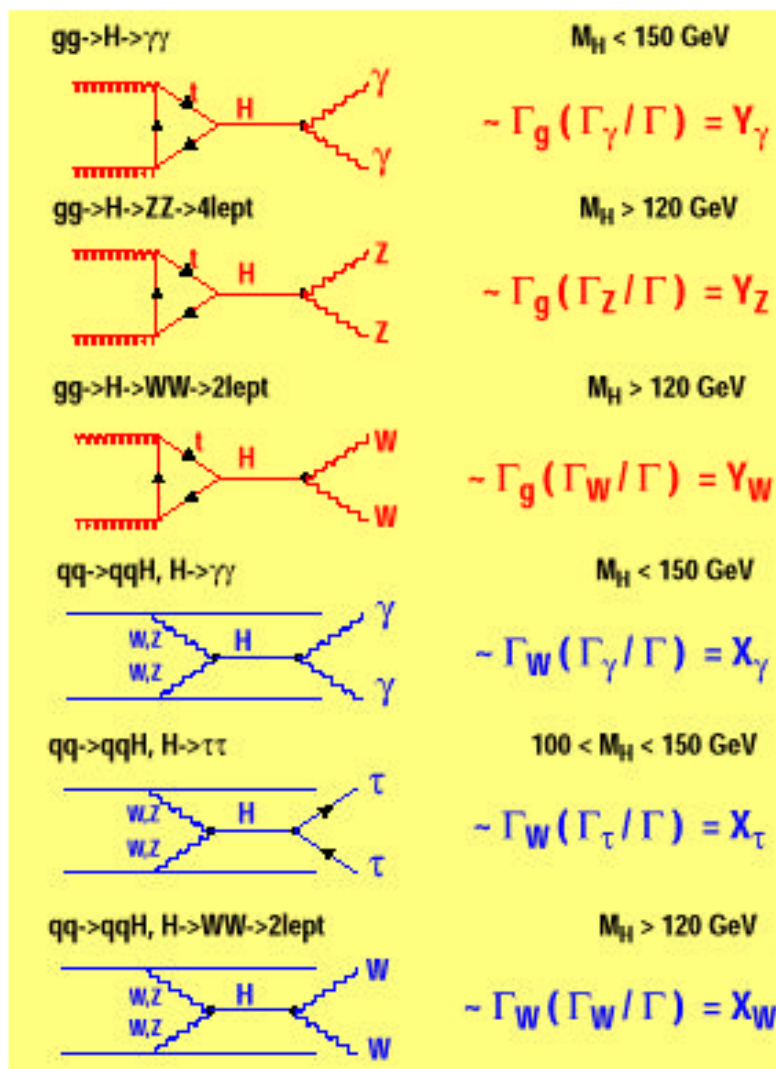


(V.Drollinger & S.Arcelli)

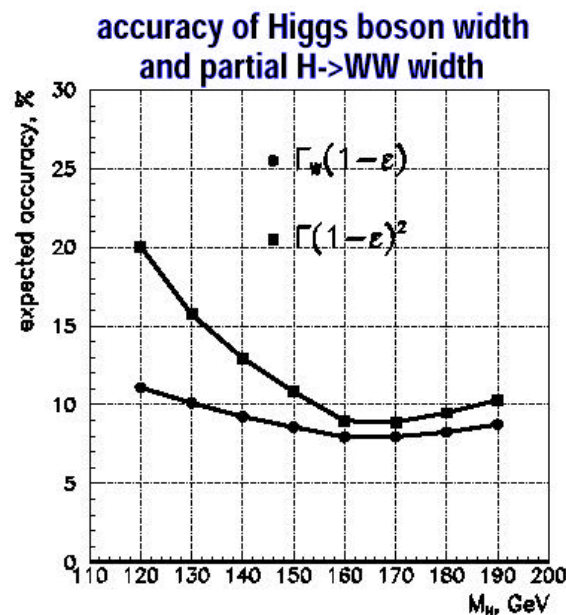


# Higgs Couplings

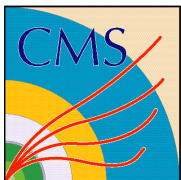
D.Zeppenfeld, R.Kinnunen, A.Nikitenko, E.Richter-Was, Phys.Rev.,D62(2000) pp13009



Accuracy expected with  $200 \text{ fb}^{-1}$  of data with ATLAS+CMS detectors at LHC

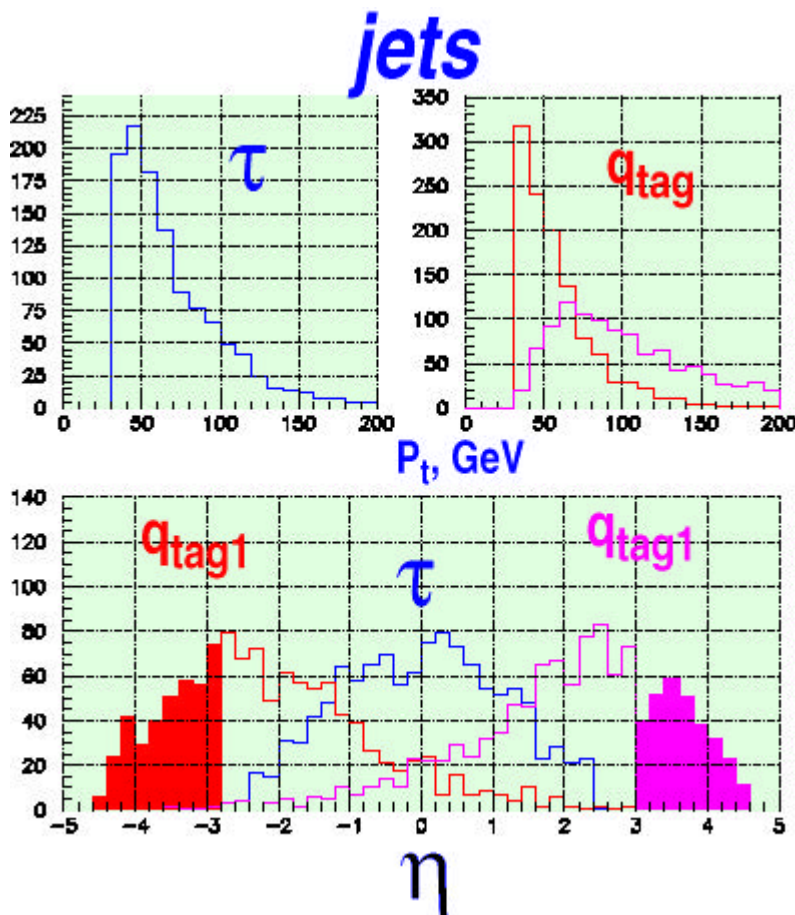


- measure  $H\gamma\gamma$ ,  $H\tau\tau$ ,  $Hgg$  couplings at 10 % level
- $hWW$  coupling ( $|\sin(\beta-\alpha)|$ ) can be measured at 5% level

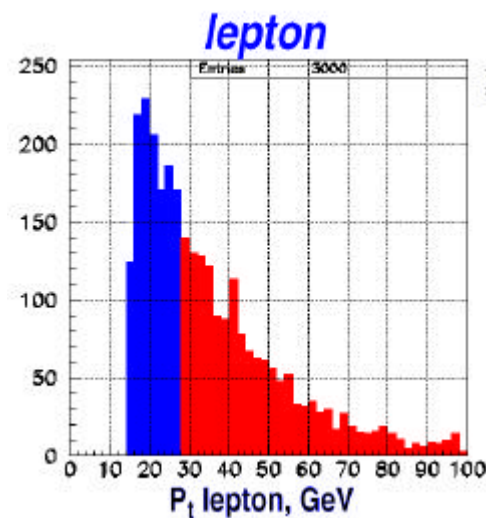


# qqH(135), $H \rightarrow 2\tau \rightarrow ej$

(A.Nikitenko)



HF acceptance for tagging jets  
( 0 / 1 / 2 ) jets = (47%,46%, 7%)  
--> need both HE and HF



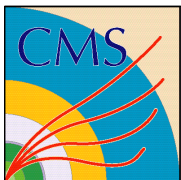
Cuts:

$E_t(e) > 15\text{GeV}$ ,  $|\eta(e)| < 2.4$   
 $E_t(\tau) > 30\text{GeV}$ ,  $|\eta(\tau)| < 2.4$   
 $E_t(q) > 40\text{GeV}$ ,  $|\eta(q)| < 5.0$   
 $|\Delta\eta(q_1q_2)| > 4.4$ ,  $M(q_1q_2) > 1\text{TeV}$   
 mini-jet veto

Result:

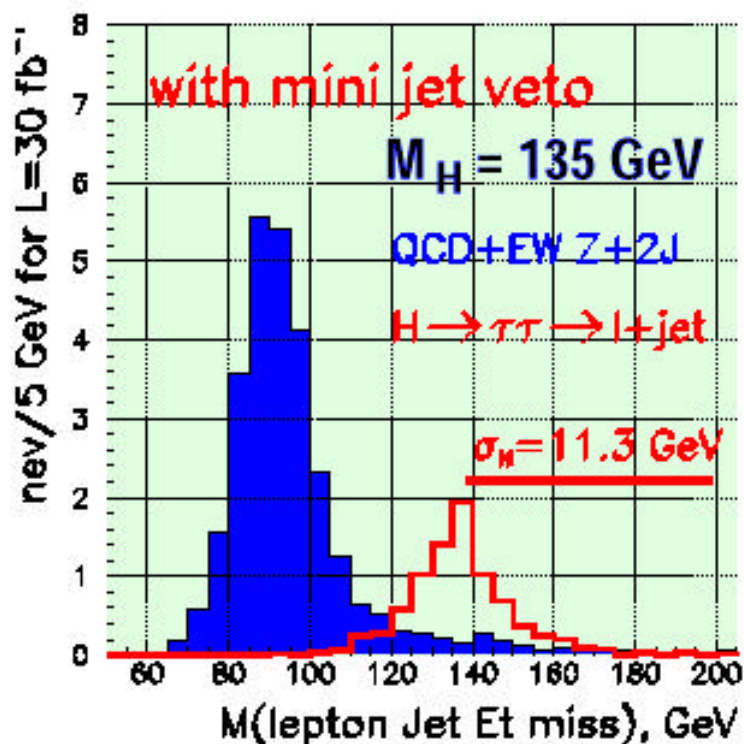
$H$  / Zjj(QCD)\*\* / Zjj(EW)\*\* / Wjjj  
 6.7+-0.3 / 0.63 / 0.74 / 0.14  
 for 30fb<sup>-1</sup>

(\*\*generated by S.Ilyin, comphep)

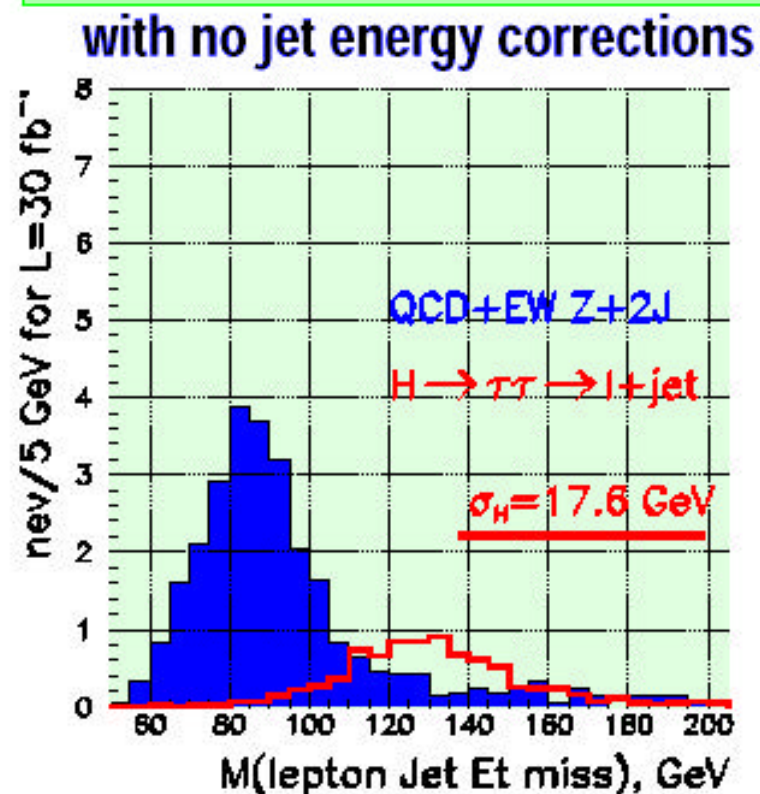


# qqH(135) : Mass Resolution

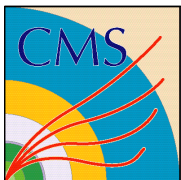
CMSJET simulation



ORCA4 simulation

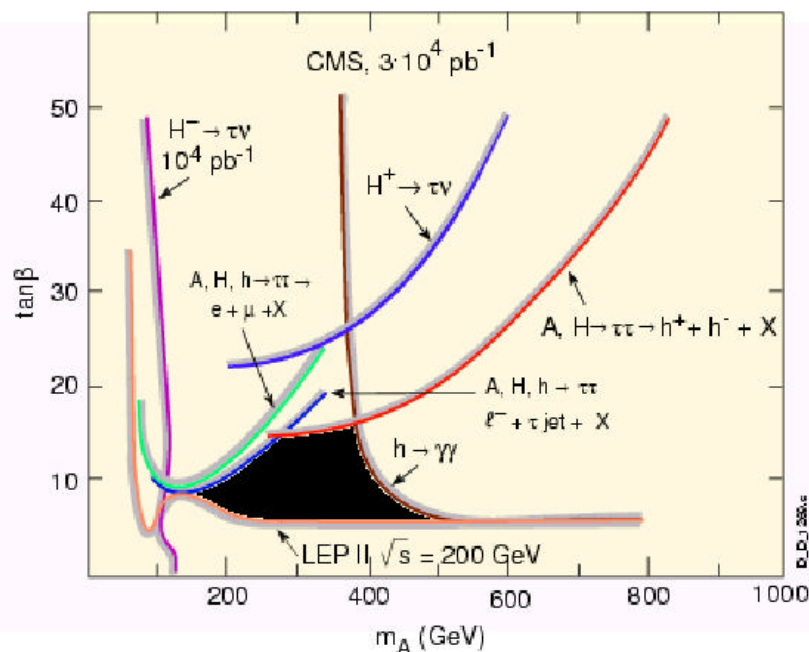


Need to improve mass with MET!



# H -> invisible

## Black Hole @ low luminosity



Need high luminosity to close the hole (with Higgs channels shown on right).

(O.J.Eboil and D.Zeppenfeld, MADPH-00-1191)

CMS has studied

$H(500) \rightarrow \tau\tau \rightarrow j+j, e+j$

$H(200) \rightarrow \tau\tau \rightarrow j+j, e+j$

$qqH(135) \rightarrow \tau\tau \rightarrow e+j$

and look promising @  $10^{34}$

More challenging channel is  
 $qqH(120-400) \rightarrow \text{invisible}$

$E_T(q) > 40\text{GeV}, |\eta(q)| < 5.0$

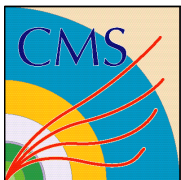
$\Delta\eta(qq) > 4.4$

$M(qq) > 1\text{TeV}$

mini jet veto

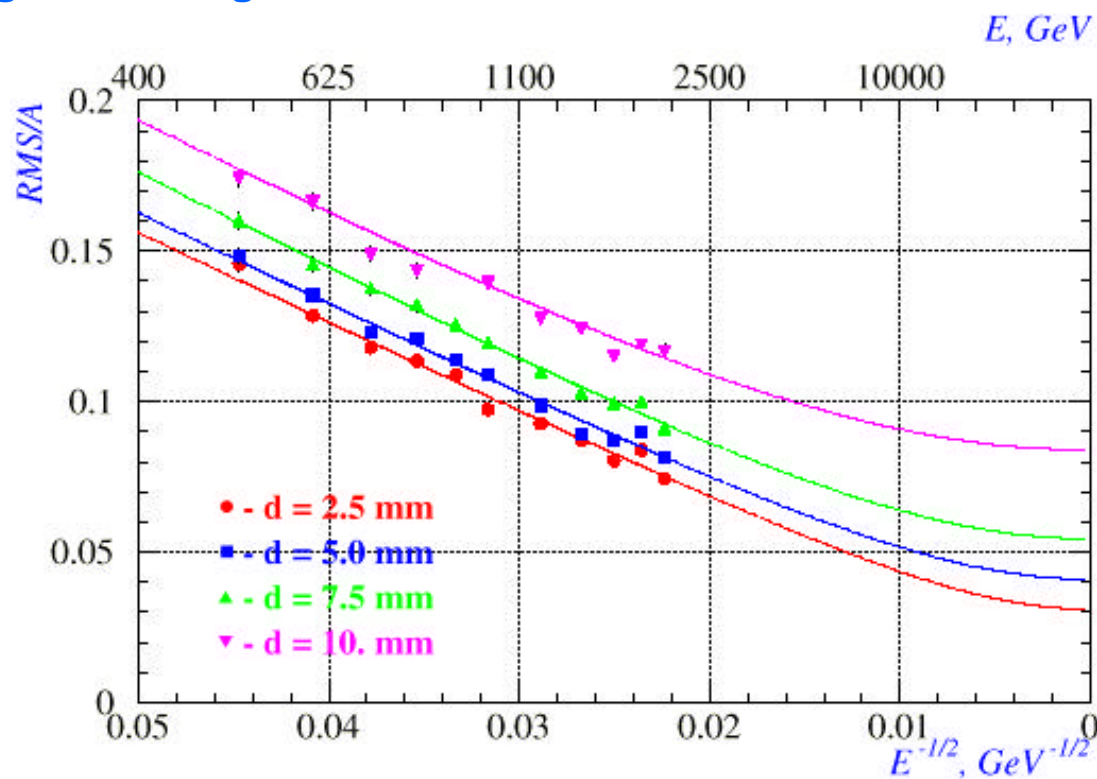
$MET > 100\text{GeV}$

Only forward jets are positive signal!



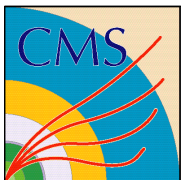
# Optimization of HF Fiber Spacing

Simulation done with test beam  
data and PYTHIA  
for two longitudinal segmentaion.



(V.Kolosov)

**5mm** spacing was chosen.



# HCAL Calibration Tools (light $\rightarrow$ ADC $\rightarrow$ Jets/MET/tau)

## A) Megatile scanner:

- $\text{Co}^{60}$  gamma source
- each tile: light yield
- during construction  
all tiles

## B) Moving radio active source:

- $\text{Co}^{60}$  gamma source
- full chain: gain
- during CMS-open (manual)  
all tiles
- during off beam time (remote)  
tiles in layer 0 & 9

## C) UV Laser:

- full chain: timing, gain-change
- during off beam time  
tiles in layer 0 & 9  
all RBX

## D) Blue LED:

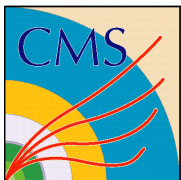
- timing, gain change
- during the off beam time  
all RBX

## E) Test beam

- normalization between  
GeV vs. ADC vs. A,B,C,D
- ratios: elec/pion, muon/pion
- before assembly  
a few wedges

## F) Physics events (in-situ)

- mip signal, link to HO  
muon
- calo energy scale (e/pi)  
charged hadron
- physics energy scale  
photon+jet balancing  
Z+jet balancing  
di-jets balancing  
di-jet mass  
W $\rightarrow$ jj in top decay  
>> non-linear response  
>> pile-up effect



# One Scenario (HB/HE)

(same to HF)

## 1) Before megatile insertion

- megatile scanner: **all tiles**
- moving wire source: **all tiles**

## 2.1) After megatile insertion

- moving wire source: **all tiles / 2 layer**
- UV laser: **2 layers/wedge**

## 2.2) After megatile insertion

- test beam: **a few wedges.**

**Absolute calib.  
Accuracy of 2%  
for single particle**

## 3) Before closing the CMS

- moving wire source: **all tiles**
- UV laser & blue LED: **all RBX**  
(do 3, about once/year)

## 4) Beam off times

- moving wire source: **2layer/wedge**
- UV laser: **2 laer/wedge**
- UV laser & blue LED: **all RBX**

**Monitor for change  
with time  
Accuracy < 1%**

## 5) Beam on (in situ)

- jets / tau / MET **ECAL+HCAL**

**once/month  
a few times/day (?)**



# In Situ Calibration

## (Physics Event Trigger)

### A) Min-bias events trigger

- estimation of pile-up energy.
- normalization within each eta-ring.
- isolated low  $E_T$  charged tracks

2% accuracy  
with 1k events  
in HF

### B) QCD Jet trigger (pre-scaled)

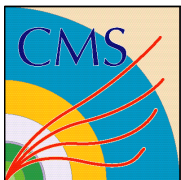
- normalization within each eta-ring
- normalization at the HB-HE-HF boundary
- test on uniformity over full range.
- dijet balancing to normalize  $E_T$  scale in rings.

### C) tau trigger

- isolated high  $E_T$  charged tracks ( $E_T > 30\text{GeV}$ )

### D) muon trigger (isolated)

- good for monitoring.
- probably too small energy deposit for calibration.



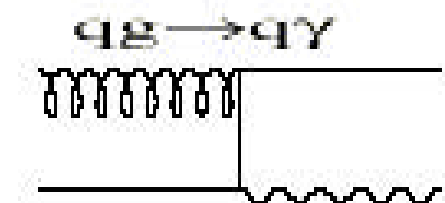
## In Situ Calibration (2)

### E) 1 photon + 1 jet

- $E_T$  Scale over full range by photon-jet balancing

Note:

- depend on ECAL  $E_t$  scale
- sensitive to ISR (& FSR)

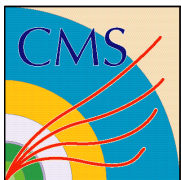


### F) Z ( $\rightarrow ee, \mu\mu$ ) + 1 jet

- $E_T$  Scale over full range by Z-jet balancing

Note:

- depend on Tracker and/or ECAL
- sensitive to ISR (& FSR)



# Photon-Jet balancing for HF Jets

E.Dorshkevich, V.Gavrilov  
CMS Note 1999/038

Using  
 $Et(\gamma) > 40\text{GeV}, |\eta(\gamma)| < 2.4$

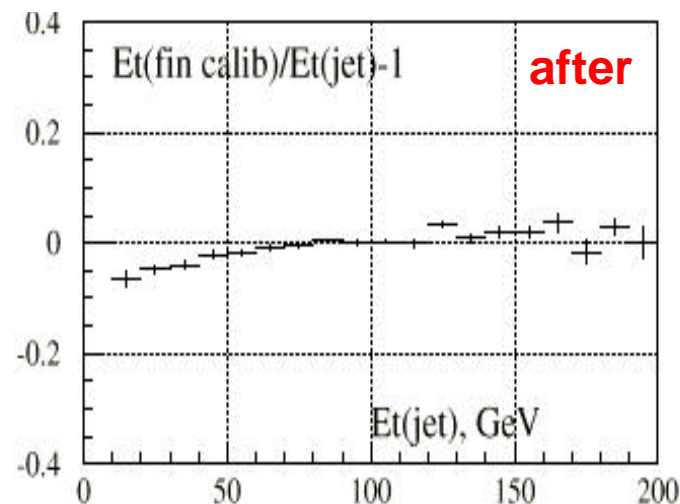
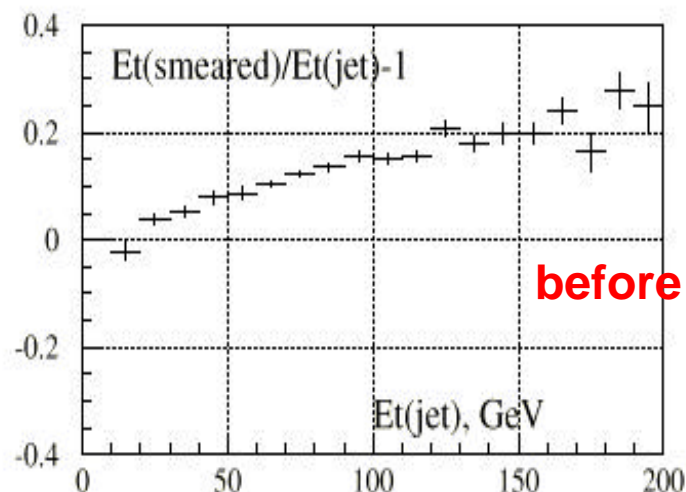
- minimize MET with 4000  $\gamma$

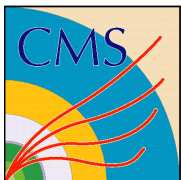
$$Et(\text{calib}) = C_{(S)}(\eta) Et_{(\text{Short})} + C_{(L)}(\eta) Et_{(\text{Long})}$$

- 2.3 days at 10E33  
with 1% efficiency

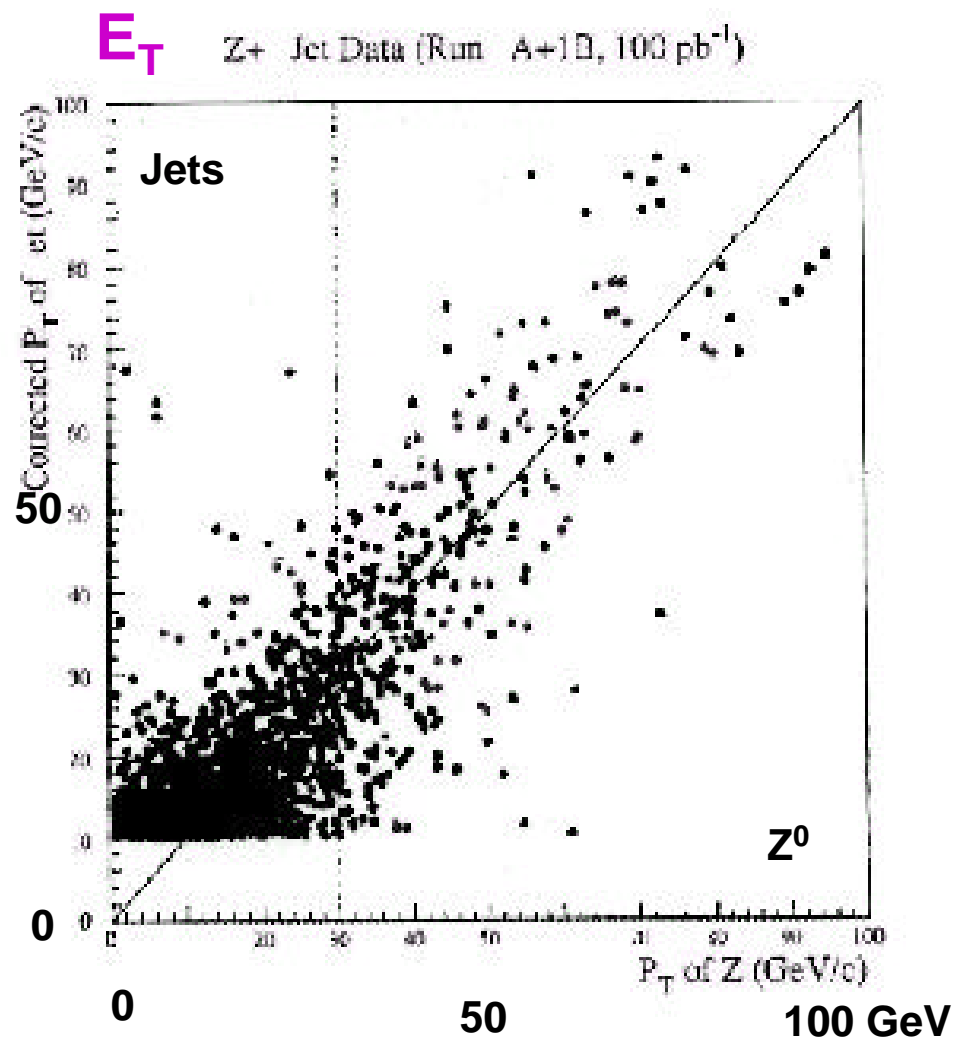
Accuracy < 1-5% for  $Et > 40\text{GeV}$

(tagging jets)





# Z (ee, $\mu\mu$ ) - jet balancing



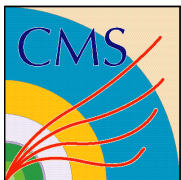
Freeman & Wu (Fermilab-TM-1984)

**CDF Data (100pb<sup>-1</sup>) :**  
**energy scale accuracy**  
**to 5% for  $E_T > 30$  GeV**

**CMS:**

**700k events/month**  
**at 10E33**

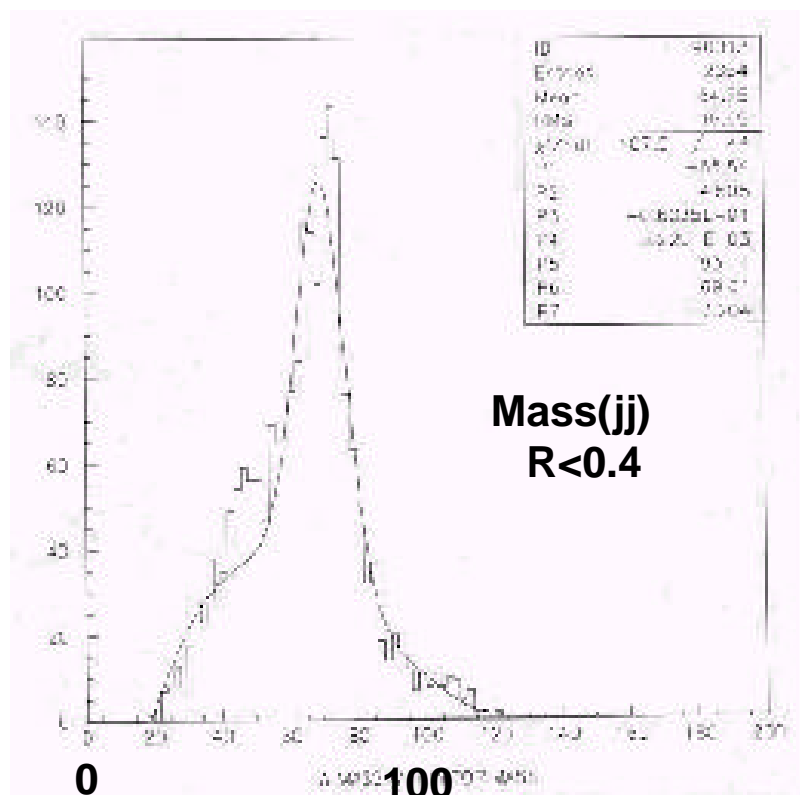
**$|\eta(\text{lep.})| < 2.6$**   
 **$E_T(\text{jet}) > 40$  GeV**



# In Situ Calibration (3)

## F) Top trigger (1 lepton + jets + 2 b-tags)

-  $E_T$  scale by Mass(jj) for W in Top decay.



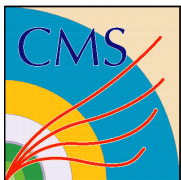
Parameterized simulation

Peak: 69.6 GeV  
sigma: 7.2 GeV

45000 events / month  
at 10E33  
with double b-tagging.

Not depend on ISR!

Freeman & Wu (Fermilab-TM-1984)



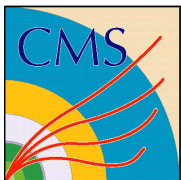
# Summary (1)

## Energy Resolution and Scale

- Simple Jet energy correction is working in MC world.
  - Need to extend it to MET and tau.
- We have been using very simple weighting method to sum energies in ECAL and HCAL.
  - look for better method(s), e.g. energy depend weights, use of fine segments in ECAL, use of Tracker, etc.
- In-situ calibration will provide absolute scale.
- Need plan to cover energy calibration up to the highest energy.

## High Luminosity

- Low  $E_T$  jets/MET ( $<100\text{GeV}$ ) at high luminosity is very challenging for both trigger and offline analyses.
  - Need good algorithms to remove fake jets and to subtract pile-up energy.



## Summary (2)

### Physics with HCAL

- Much of physics analyses depend on jets, MET and tau.
- Forward tagging jet become more and more important, e.g. studies on property of Higgs.

### Calibration and Monitoring

- Need to develop complete scenario.
- All the tools should be ready on day-1 of data taking and calibration has to be done in 1-3 months for quick publication of physics results.

### JetMET Physics Group (S.Eno)

- <http://home.fnal.gov/~sceno.main.html>
- The group is expanding. -- Need better communication.
  - Web, VRVS, local coordination.
- Next milestone: May 2001- HLT in DAQ TDR.